Friedrich-Alexander-Universität Erlangen-Nürnberg

Project status

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Funded by the European Union
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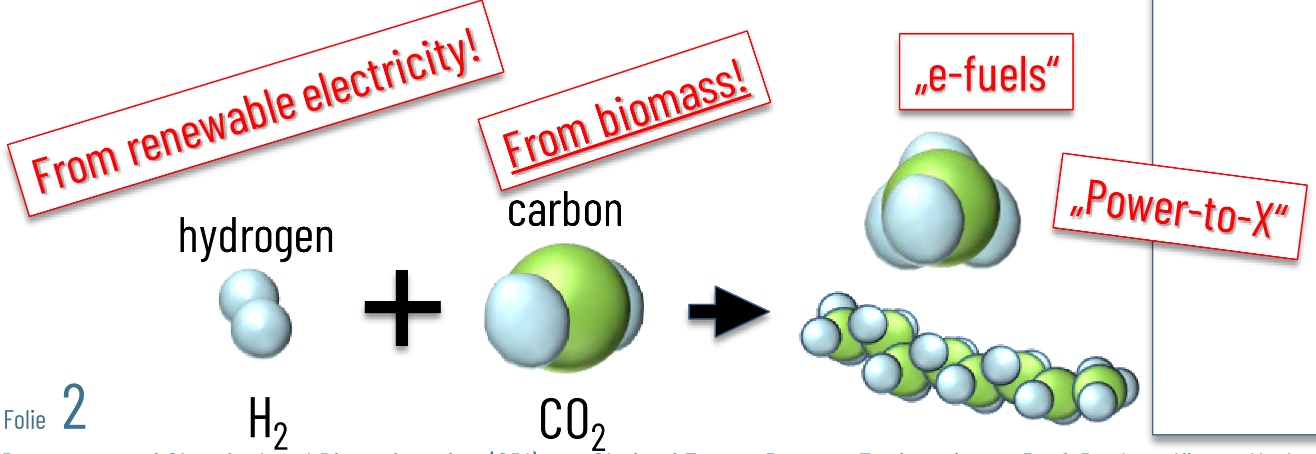
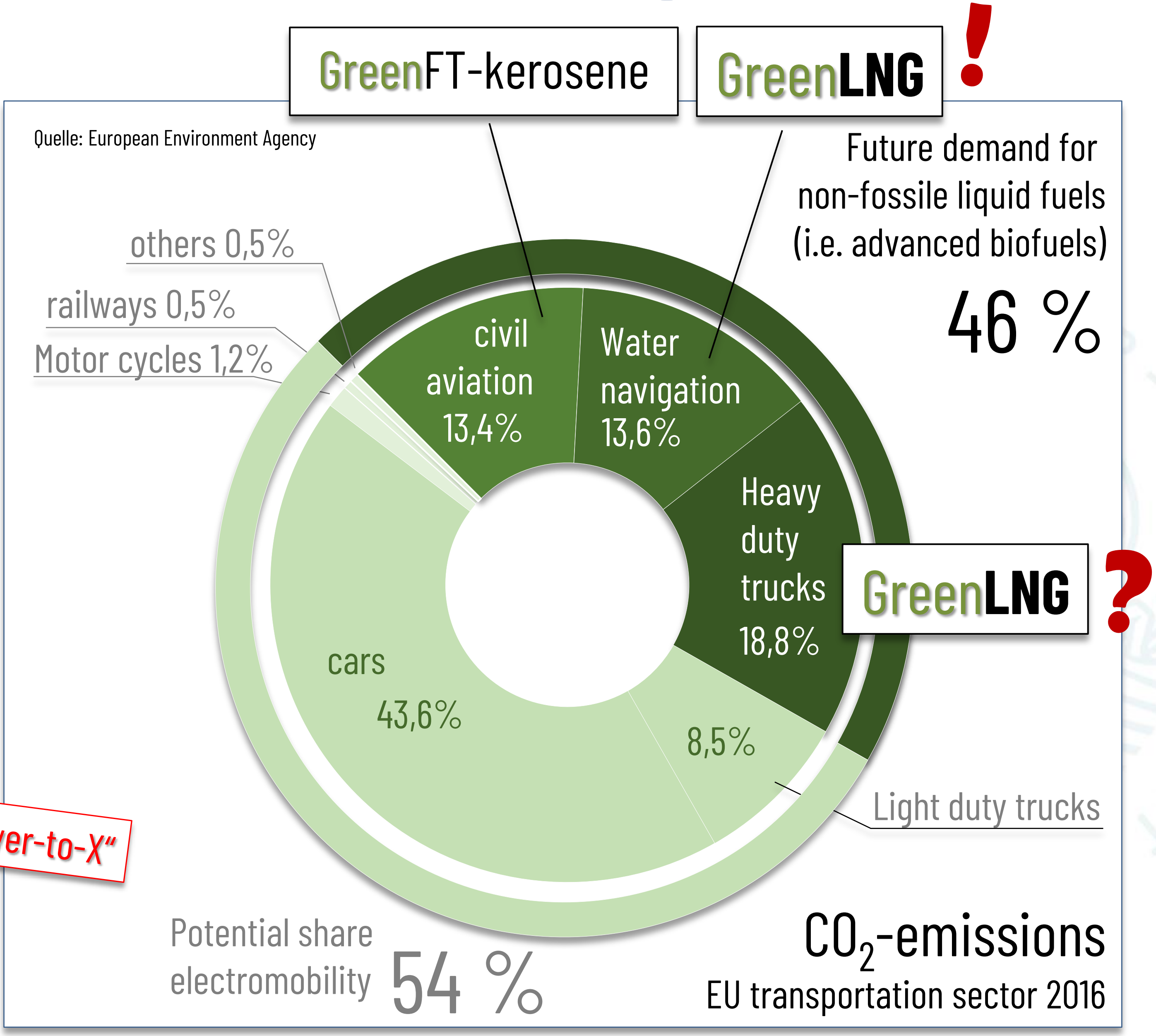
CarbonNeutralLNG

Status Quo

- Energy density of batteries is still limited
- The worldwide conversion of the existing infrastructure will certainly take decades
- **GreenLNG** is certainly the most adequate option for the **marine sector**





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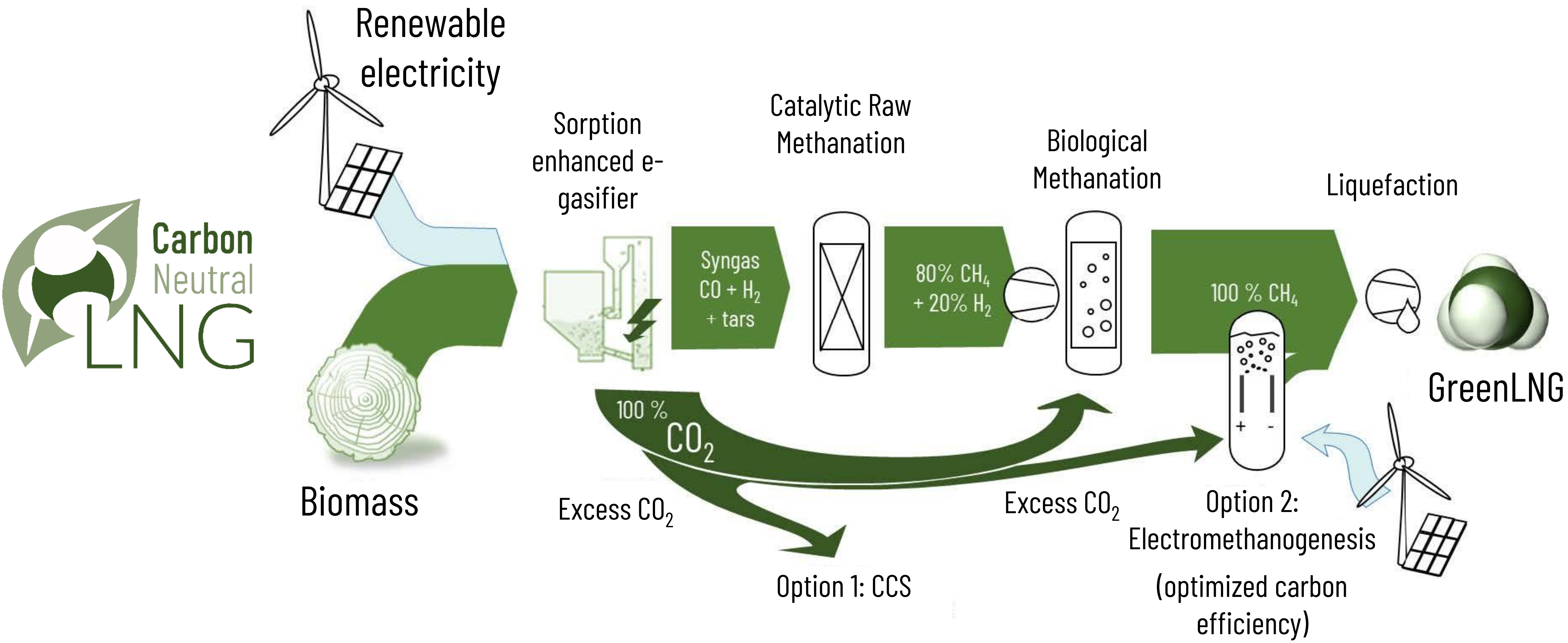
The CarbonNeutralLNG Process



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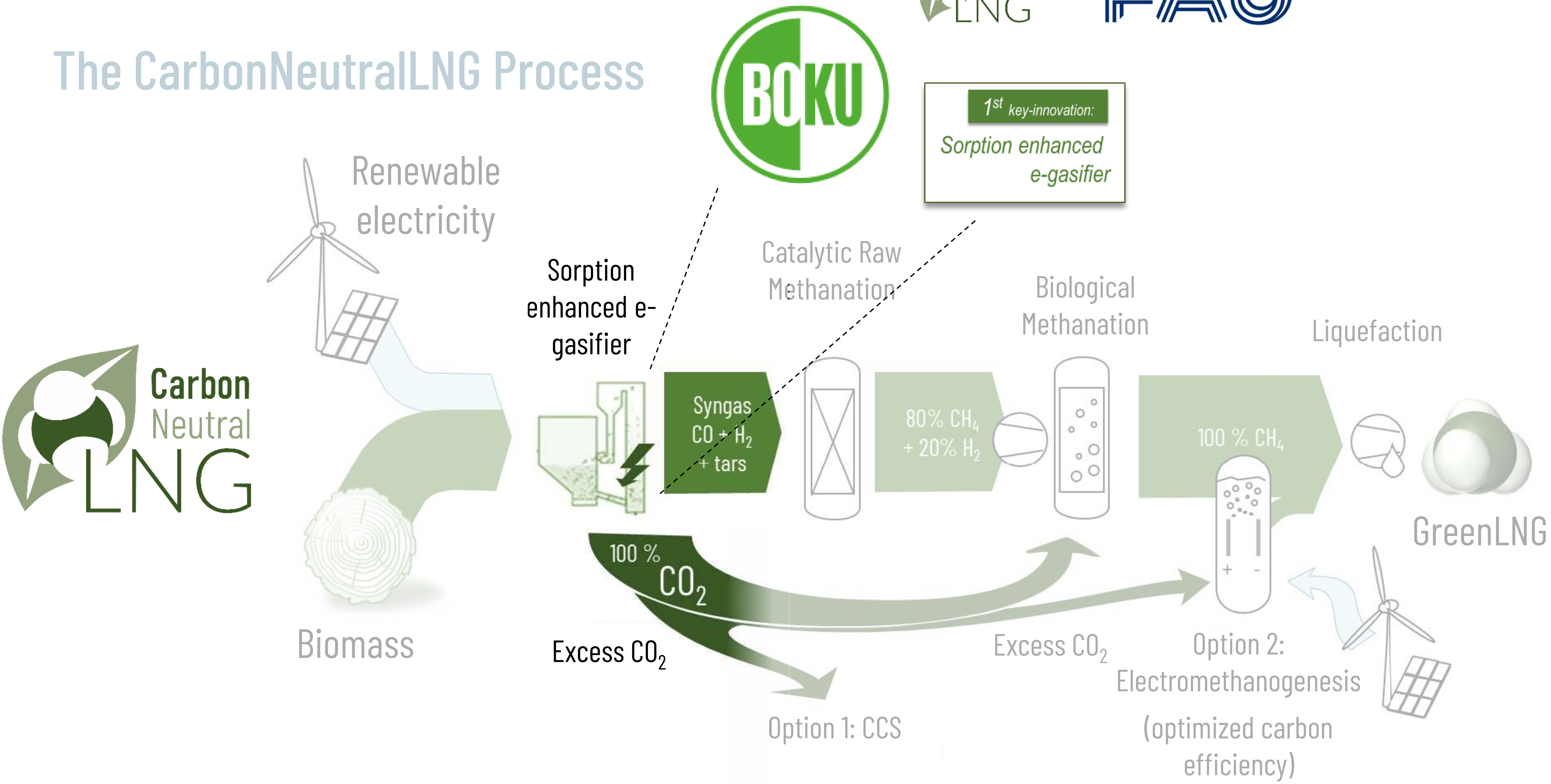

[Reference: BOKU]

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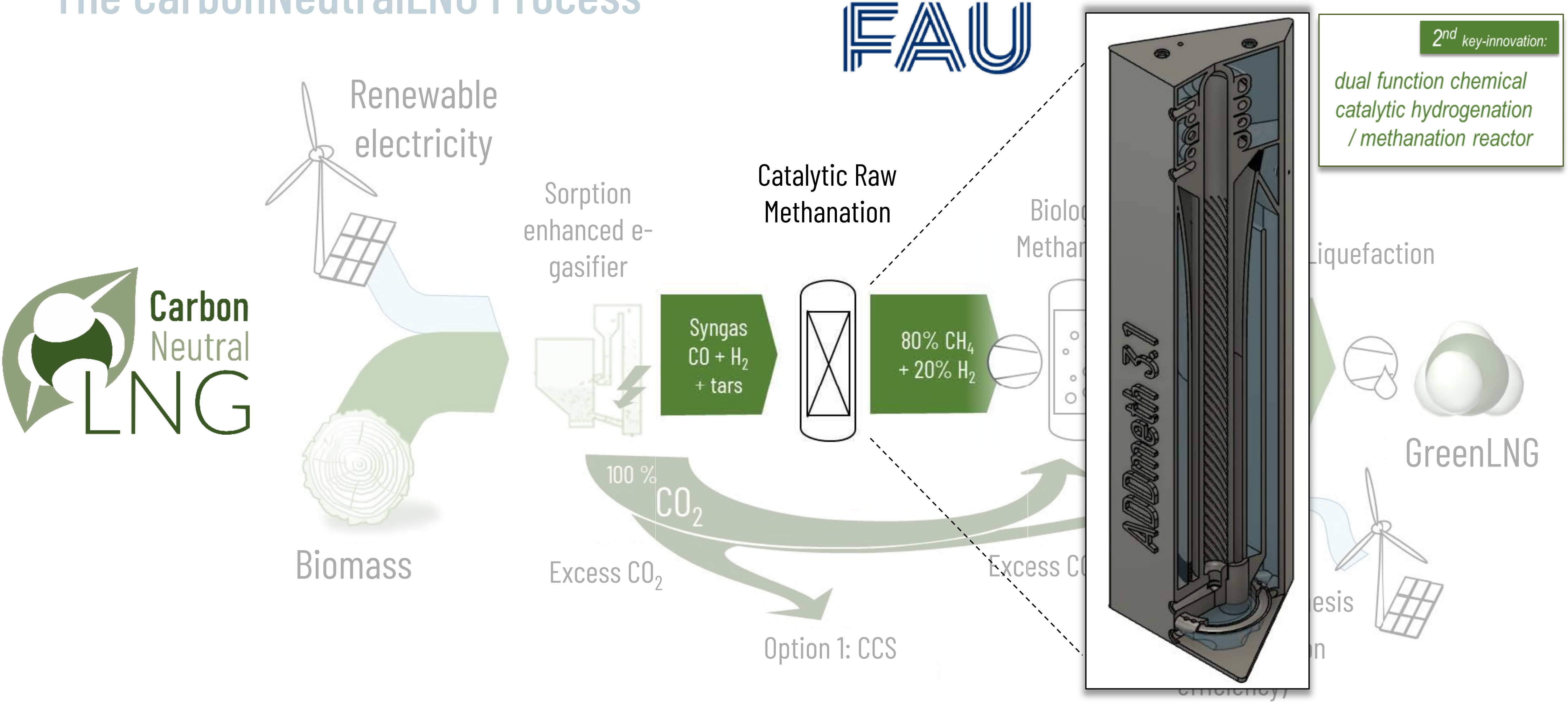

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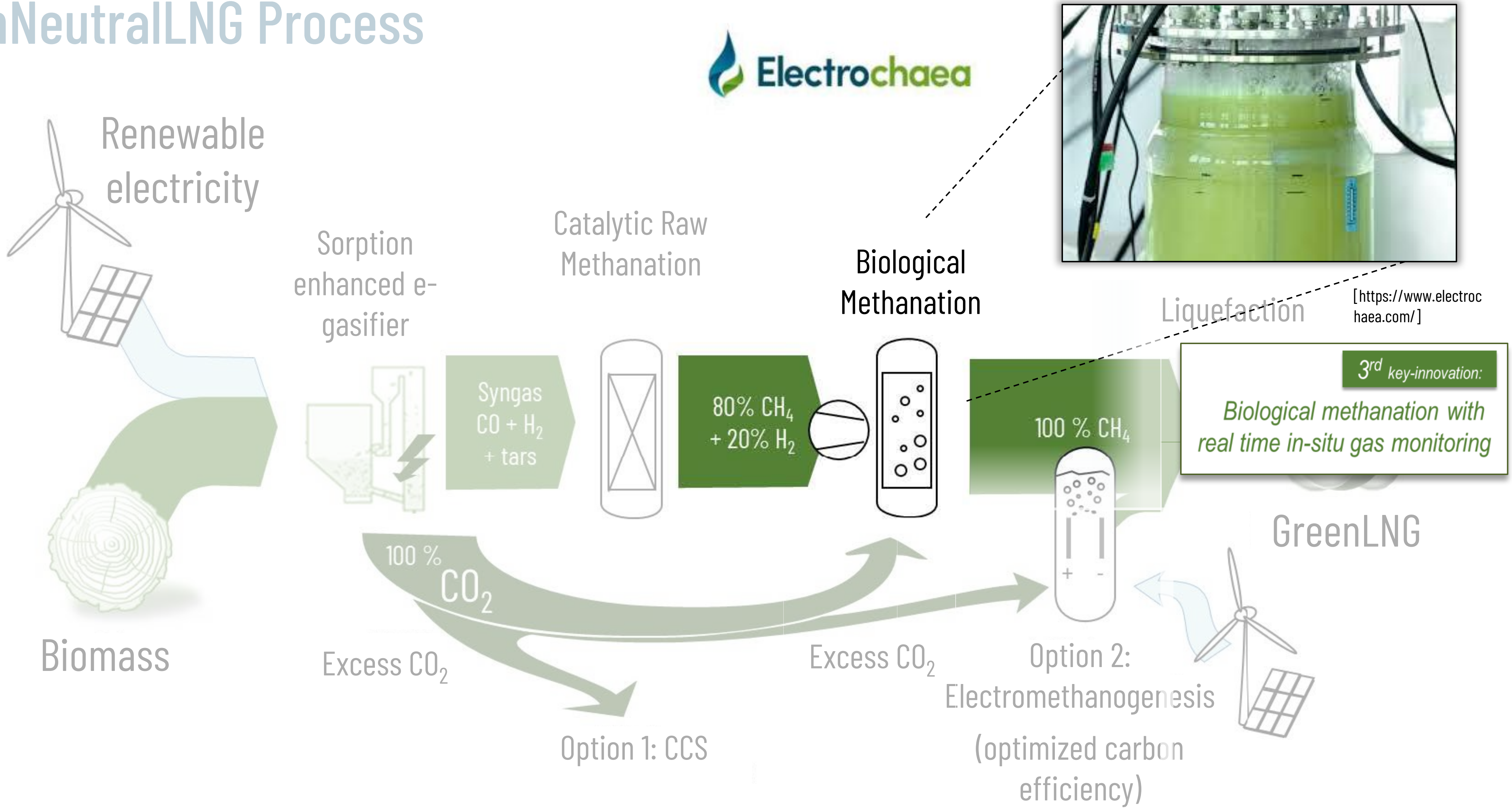

[https://www.electrochaea.com/]

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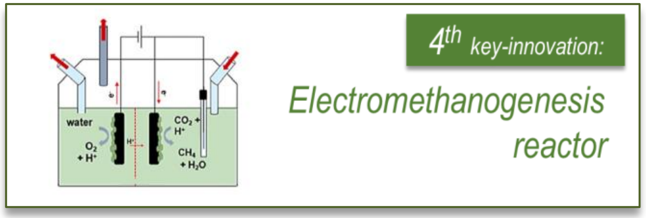

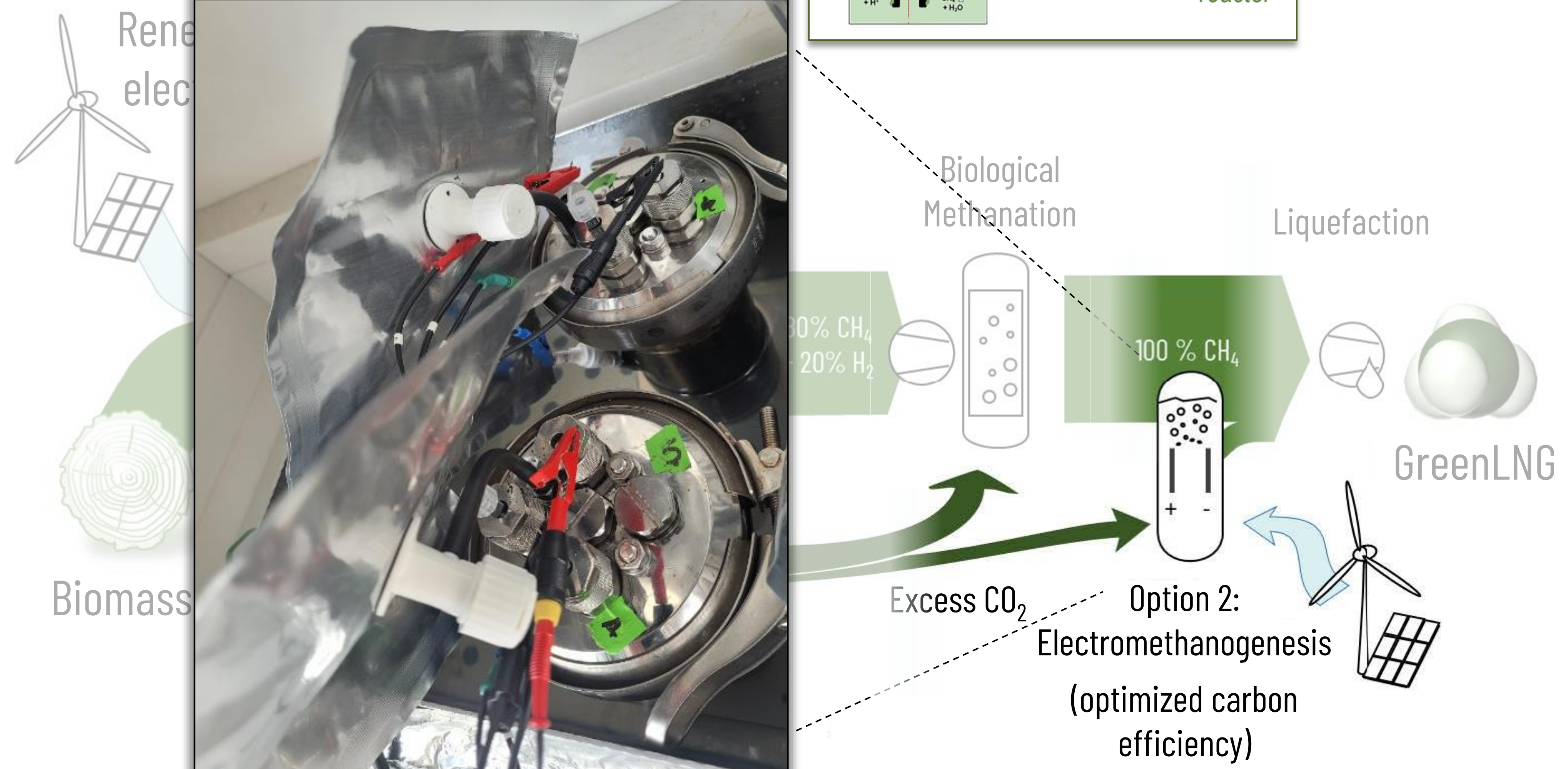

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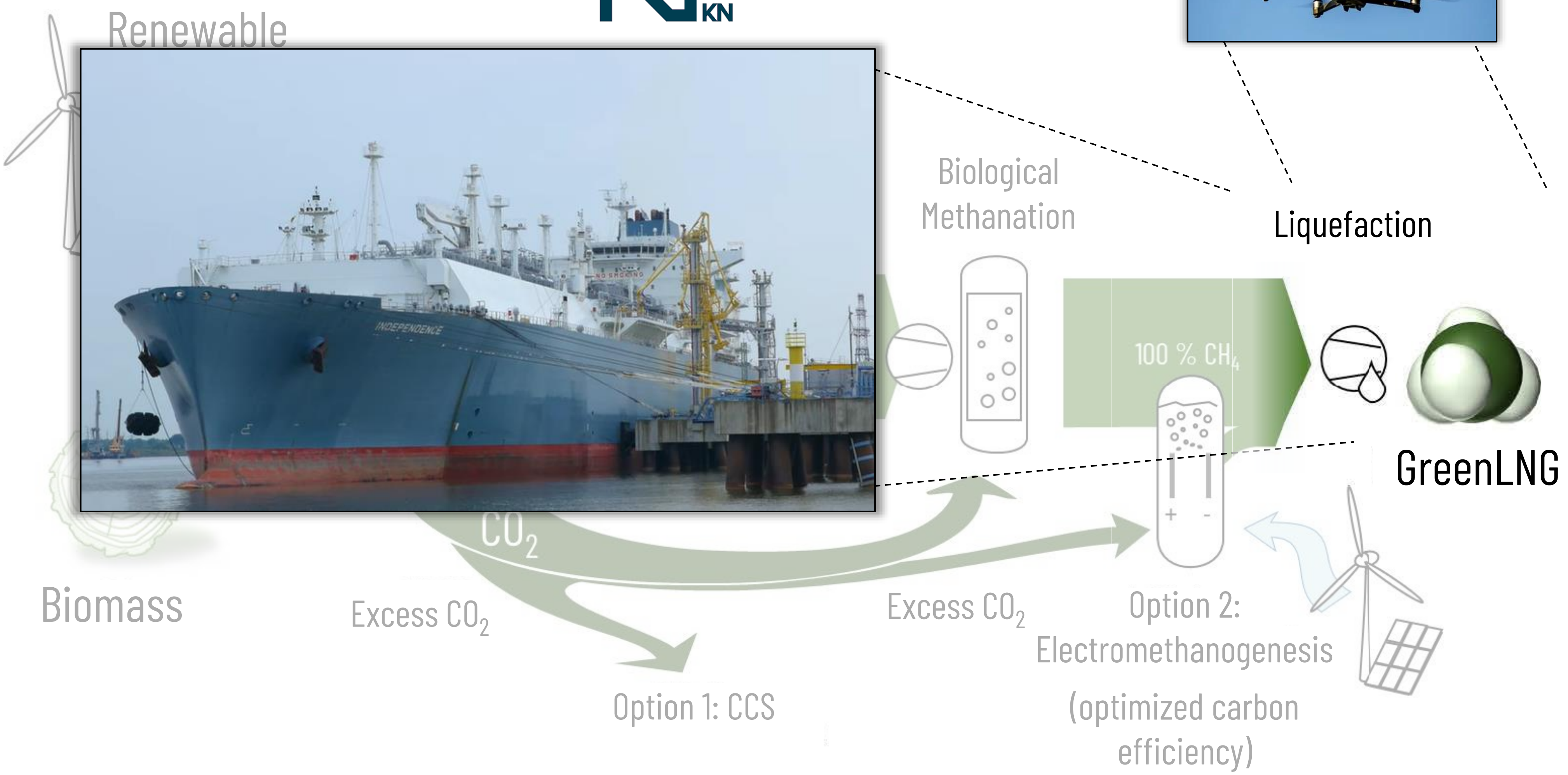
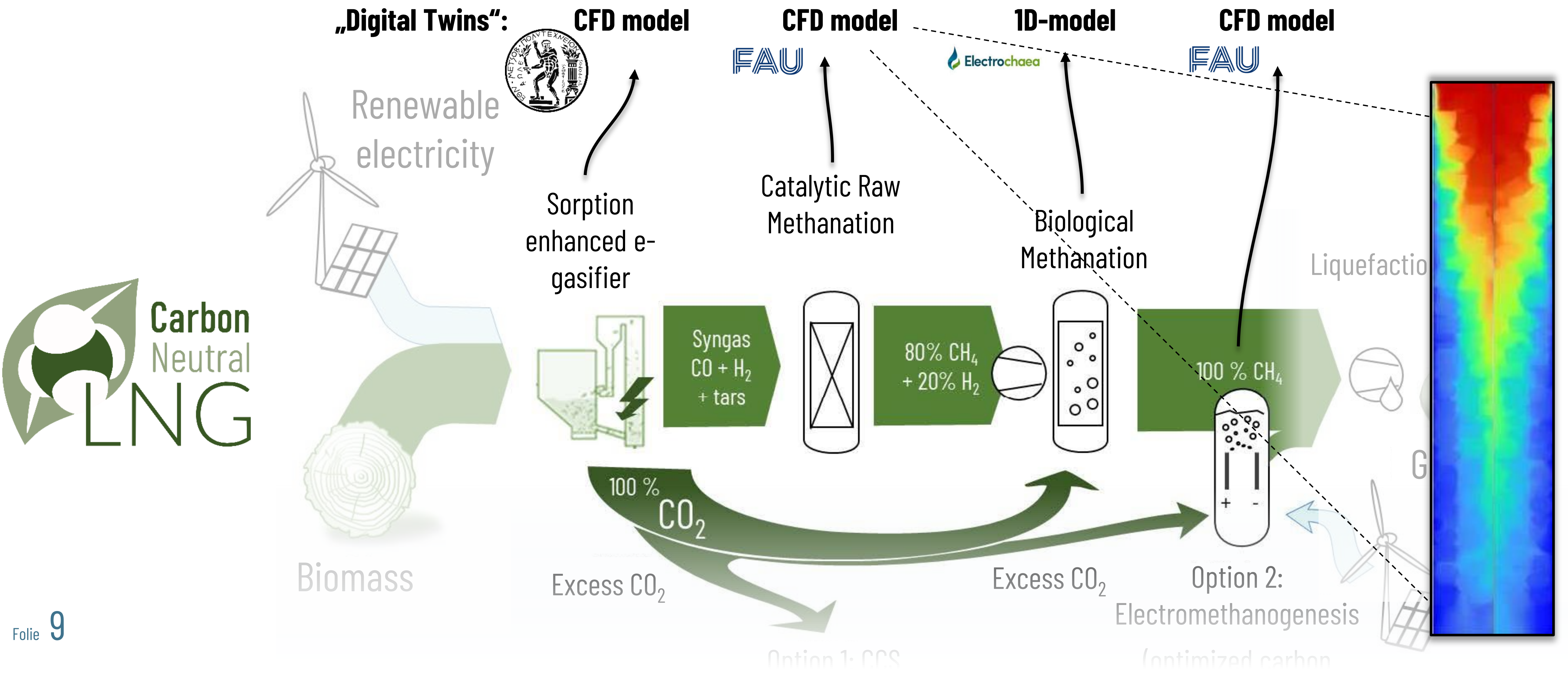


Advanced Process Control



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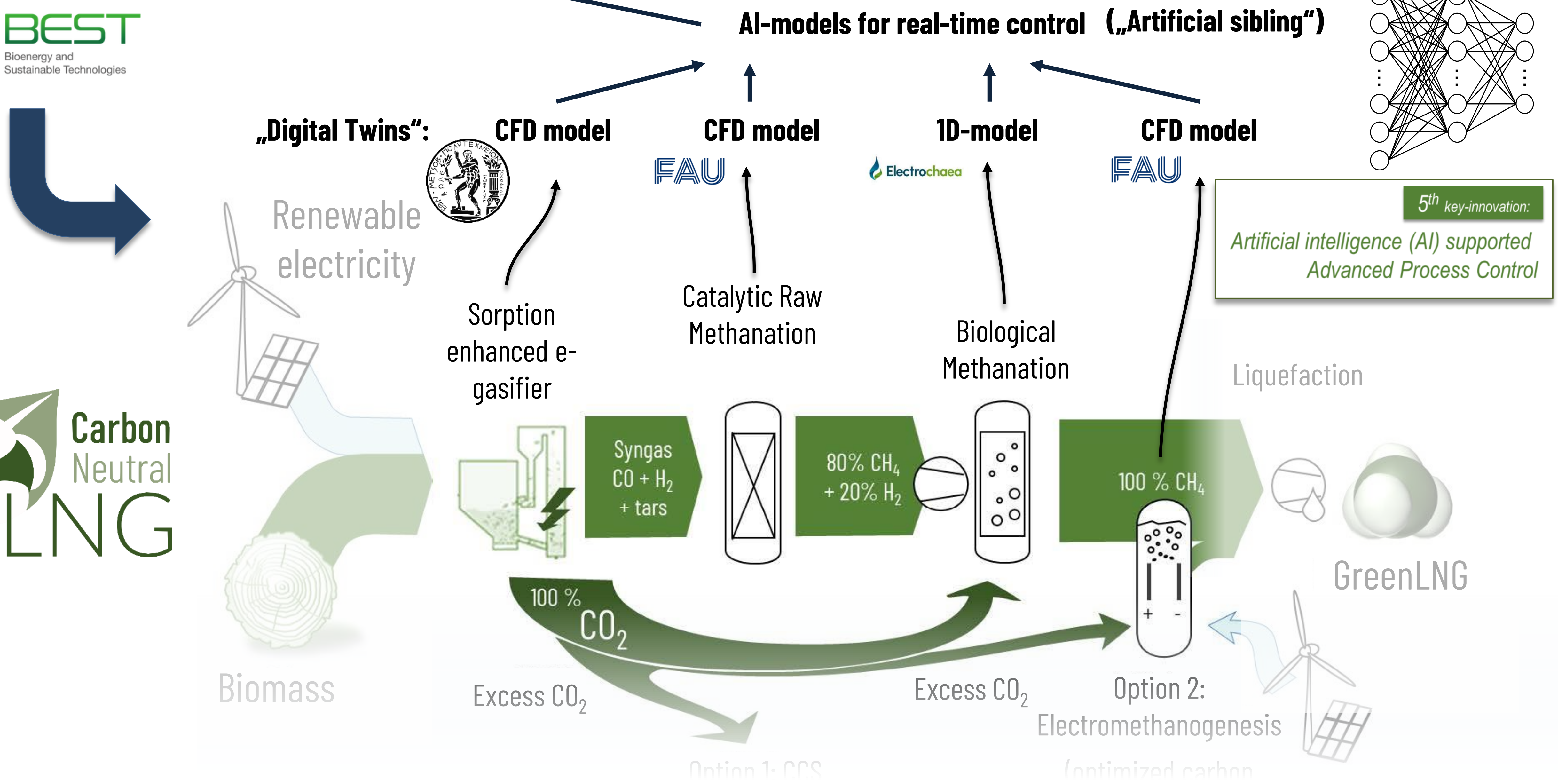
Advanced Process Control

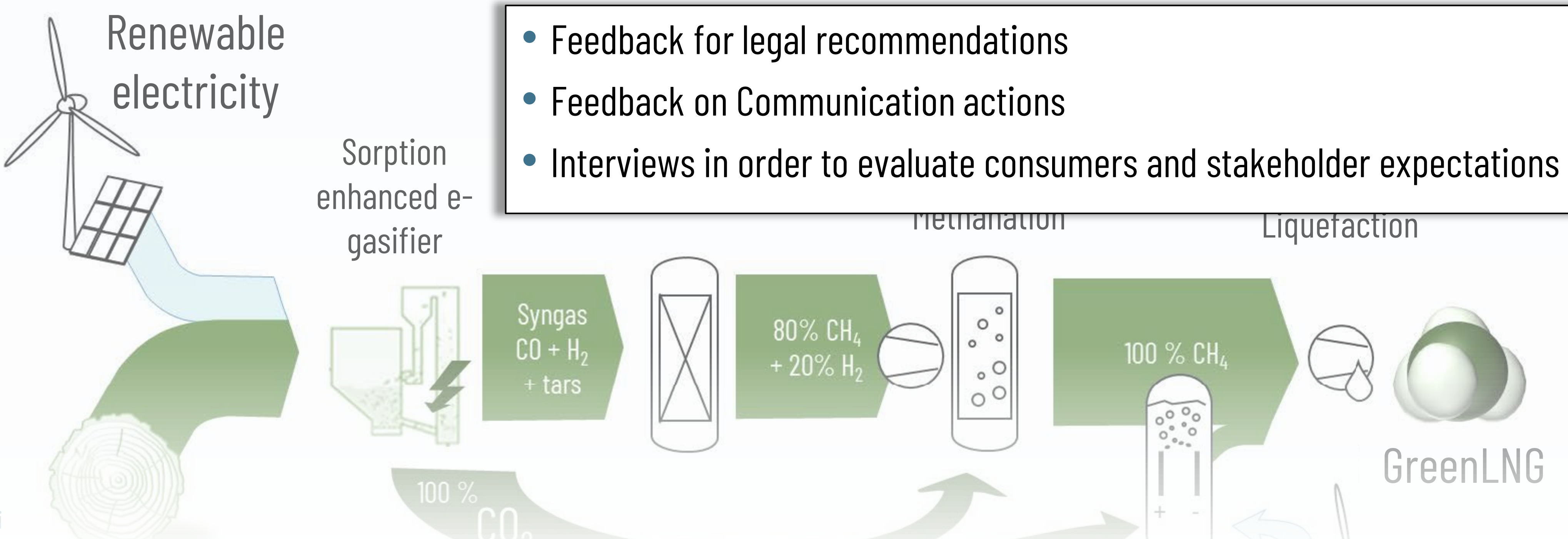


Legal, Environmental, and Economical approach:

- Impact assessment at environmental and socio-economic level
- Roadmap to replication: **market and policy** assessment
- Coordination and Dissemination

Main Role of the TTDM Board

- Feedback for legal recommendations
- Feedback on Communication actions
- Interviews in order to evaluate consumers and stakeholder expectations



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Development of an **additively manufactured catalytic methanation reactor** with **in-situ tar co-reforming**

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Carbon Neutral LNG

Funded by the European Union
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Outline

1. Methanation and co-reforming of tars
2. Preliminary designs of 3D-printed methanation reactors
3. Novel methanation reactor designs
4. Outlook

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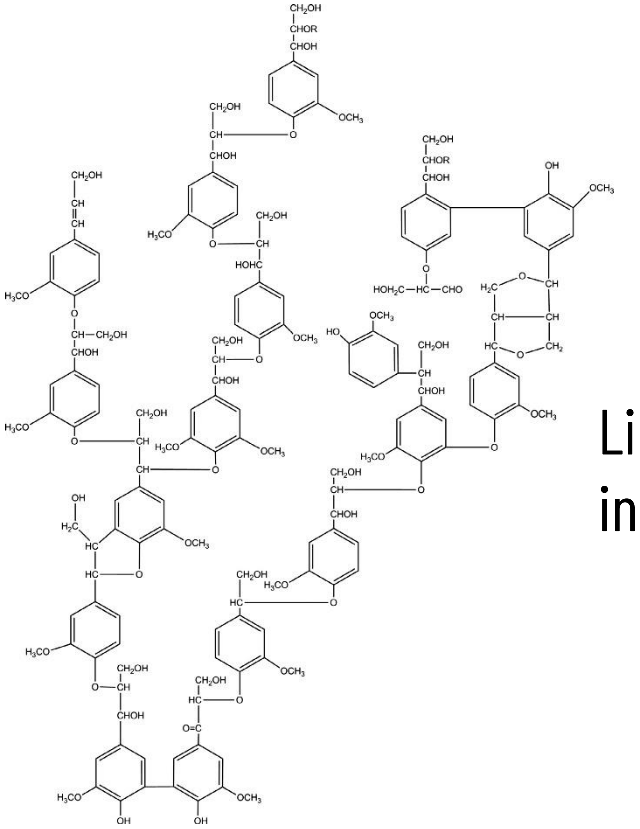
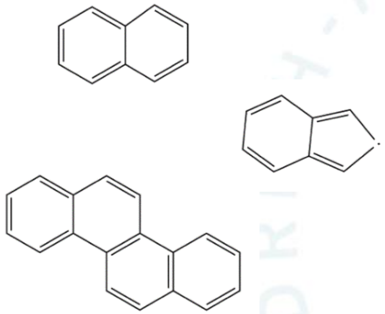
Tar development in biomass gasification

- **Tars** are **aromatic compounds** that are formed during the thermochemical gasification of biomass



Lignin from wood decomposes into aromatic tar compounds.



[1] Font Palma, C. (2013). Modelling of tar formation and evolution for biomass gasification: A review. In *Applied Energy* (Vol. 111, pp. 129–141). Elsevier Ltd. https://doi.org/10.1016/j.apenergy.2013.04.082

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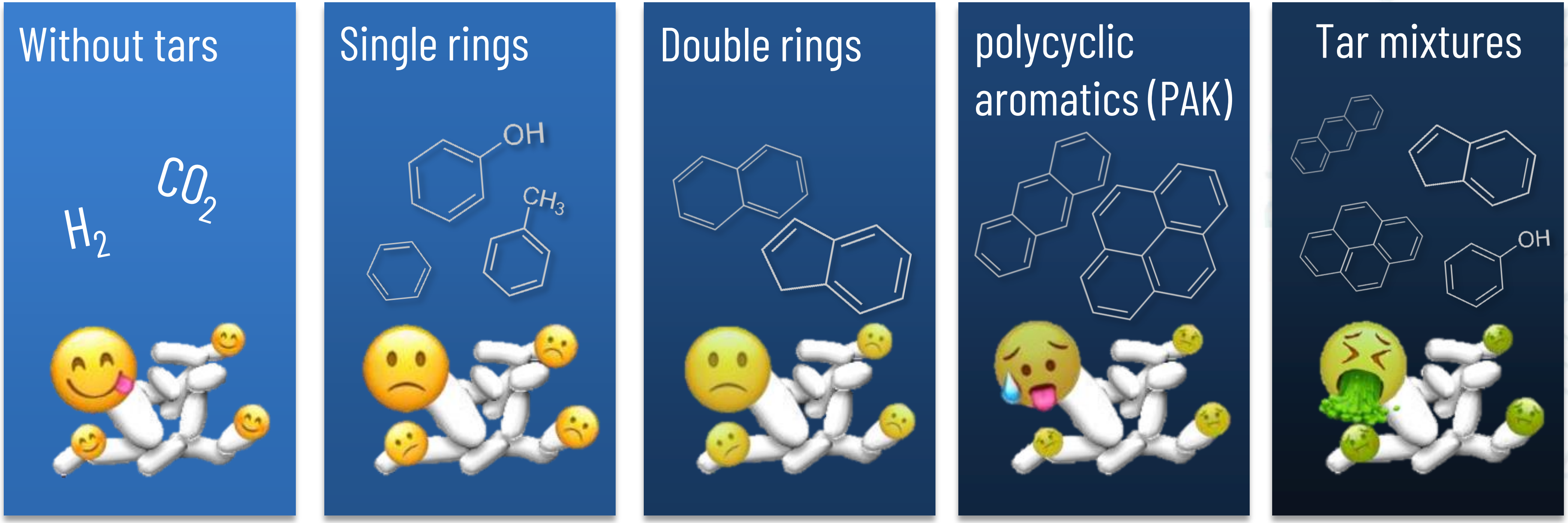
Problem with tar contamination

- Tars **condense** or **crystallize at low temperatures**, which can cause **problems in plant engineering** (deposits, blockages, etc.).
- Tars are **problematic for archaea** in biological methanation.



Removal of tars:

- **Classical gas cleaning** is **expensive** and **complex**
- Alternative: steam reforming, dry reforming, or thermal cracking

For instance, Benzene:

$$C_6H_6 + 6\,H_2O \rightarrow 6\,\boldsymbol{CO} + 9\,\boldsymbol{H_2}$$ (Steam reforming)

$$C_6H_6 + 6\,CO_2 \rightarrow 12\,\boldsymbol{CO} + 3\,\boldsymbol{H_2}$$ (Dry reforming)

- The reactions are **endothermic** and occur **at high temperatures**

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Methanation:

$$\boldsymbol{CO} + 3\,\boldsymbol{H_2} \rightarrow CH_4 + H_2O$$

- The reactions are **exothermic** and methane production favors **moderate temperatures**

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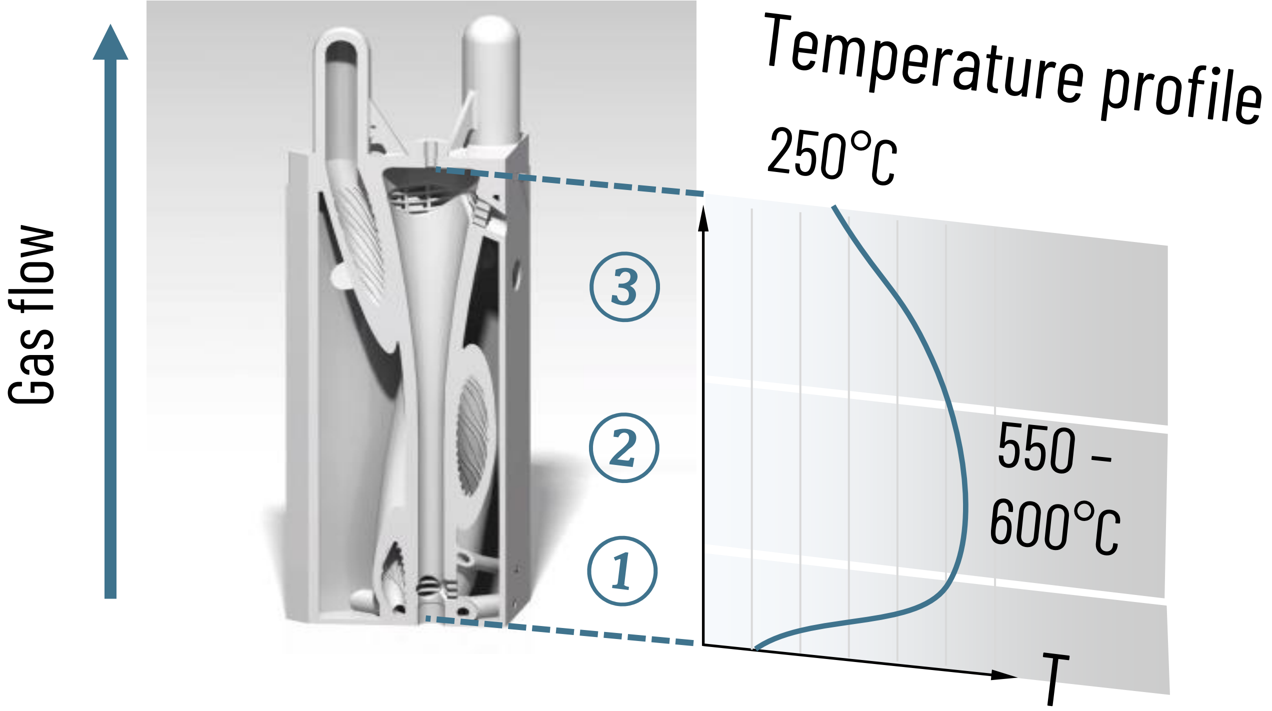
Co-reforming of tars in a methanation reactor (Advanced geometry by 3D printing to tailor temperatures)

+ Excess steam/hydrogen

Temperature profile of methanation Methanisierungsreaktion

- At the **inlet** of the reactor 1, **higher temperatures** are advantageous to improve the kinetics. The maximum operating temperature of the catalyst must be considered.
- In the **high-temperature** zone 2, there are good conditions for the **reforming of tars**

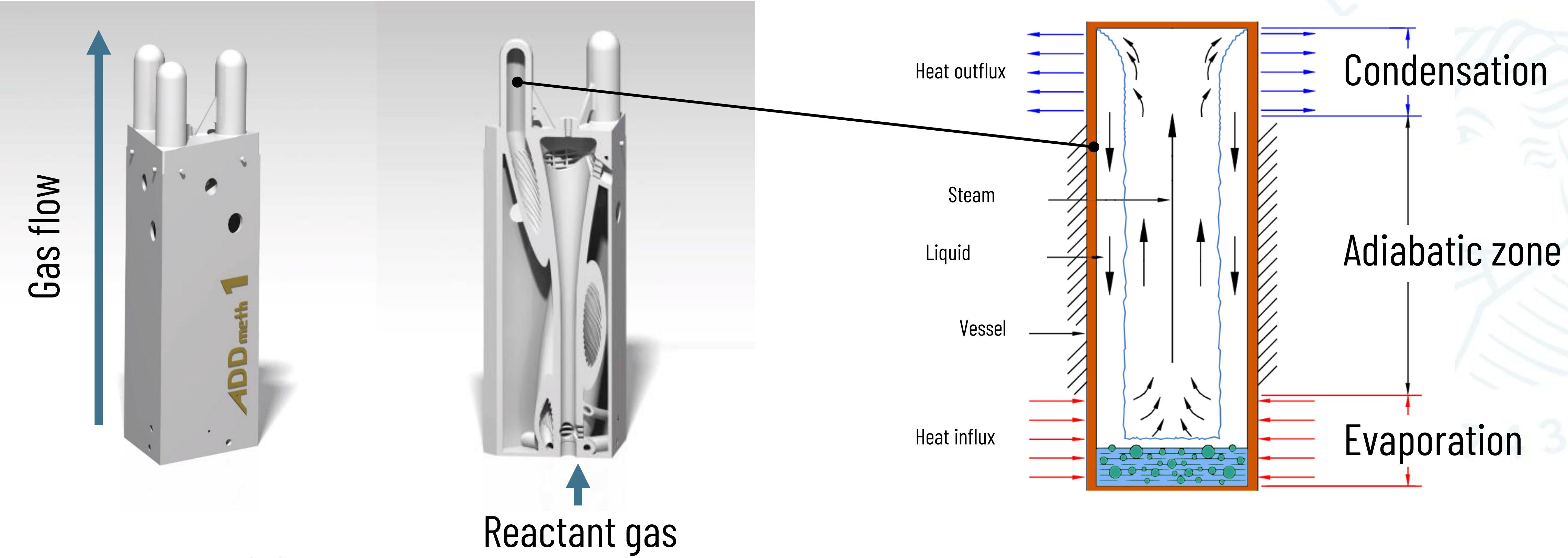


- At the **outlet** of the reactor 3, the **temperatures should drop to around 250°C** to achieve a high methane yield.

ADDmeth1 via additive manufacturing

- The **reaction channel** is **widened** at the top of the reactor to prevent kinetic limitation at the outlet
- The **conical reaction channel** maintains **temperatures at the outlet at the required level**.

- **Heatpipes** for cooling



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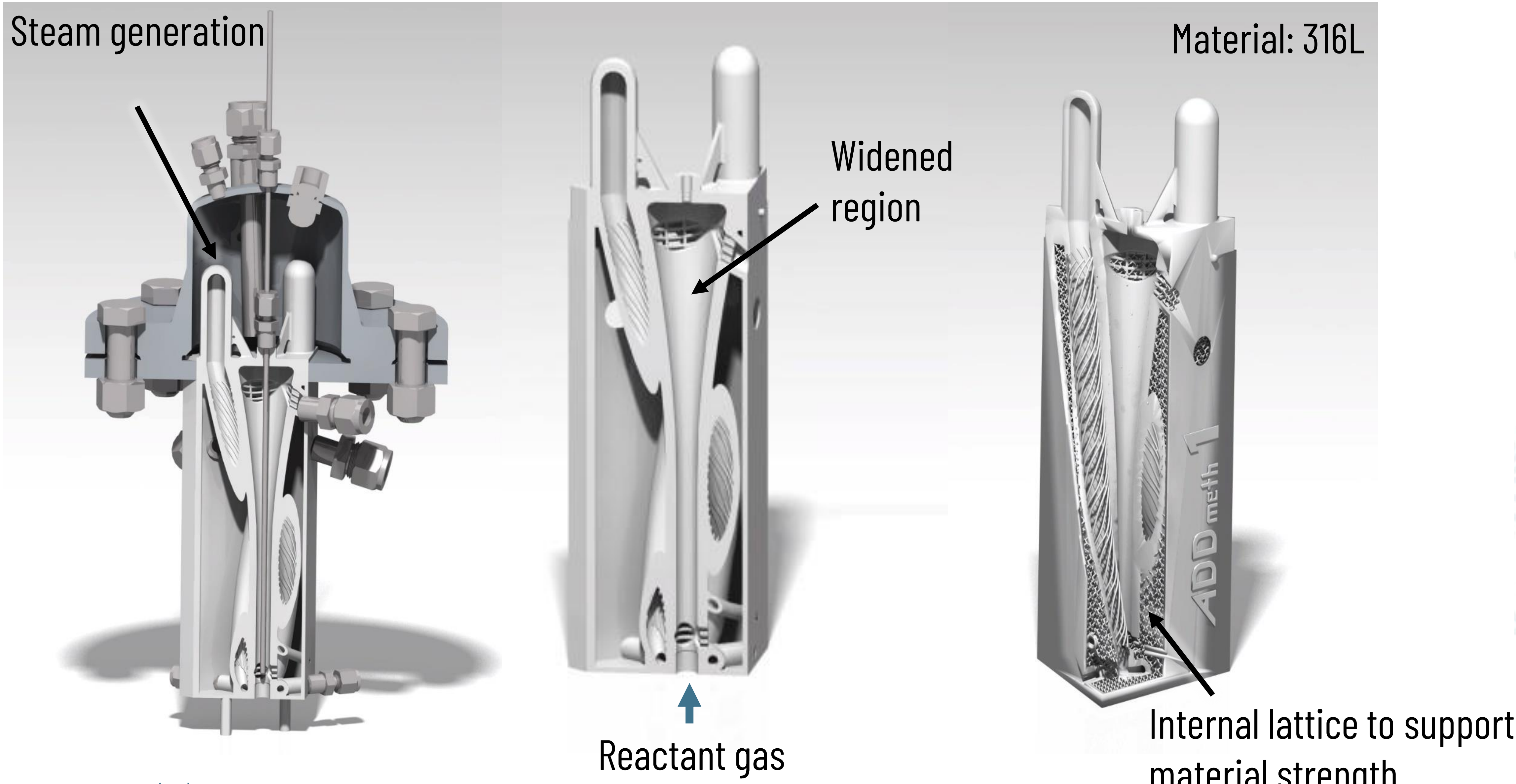
ADDmeth1 via additive manufacturing



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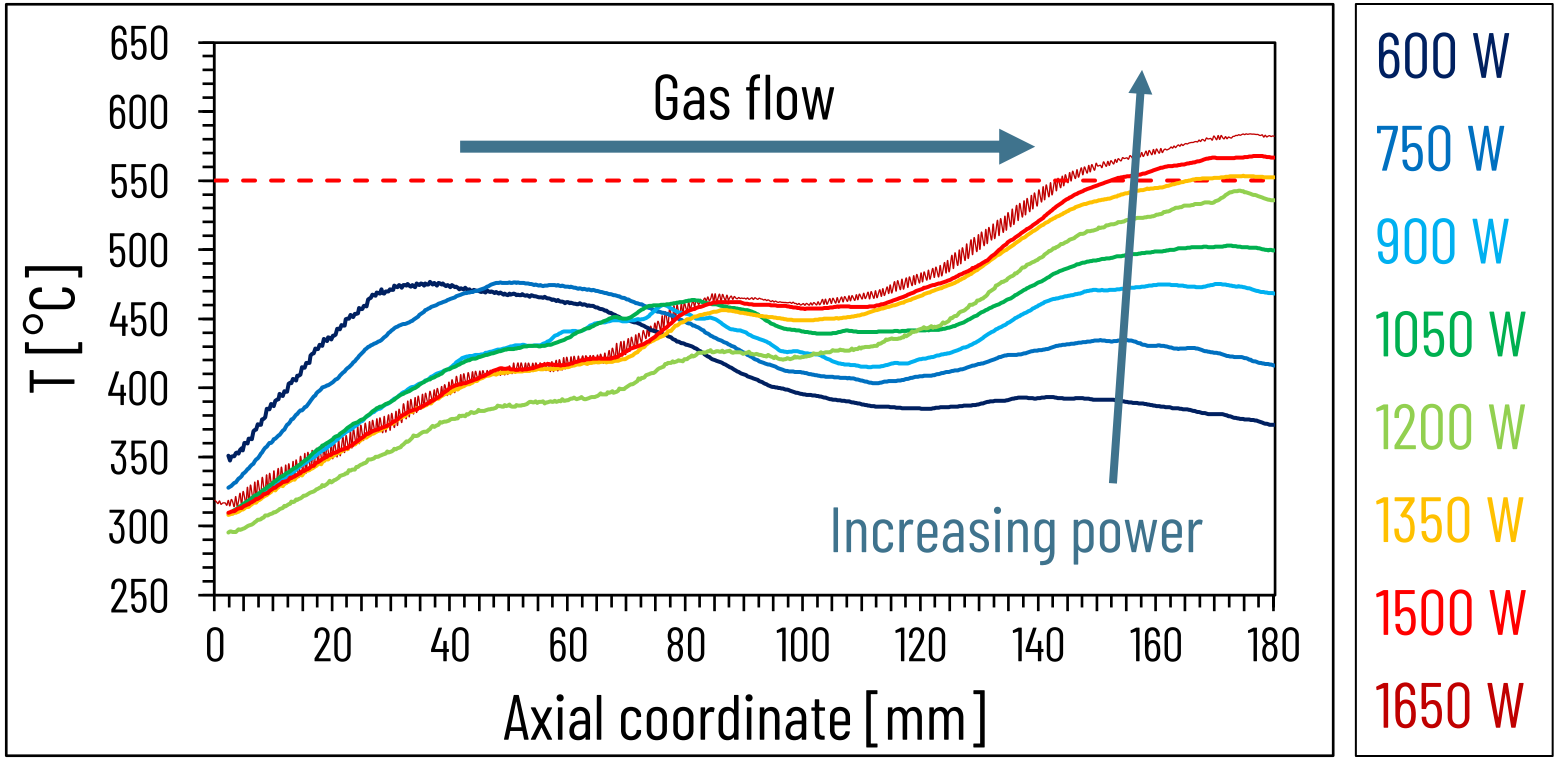
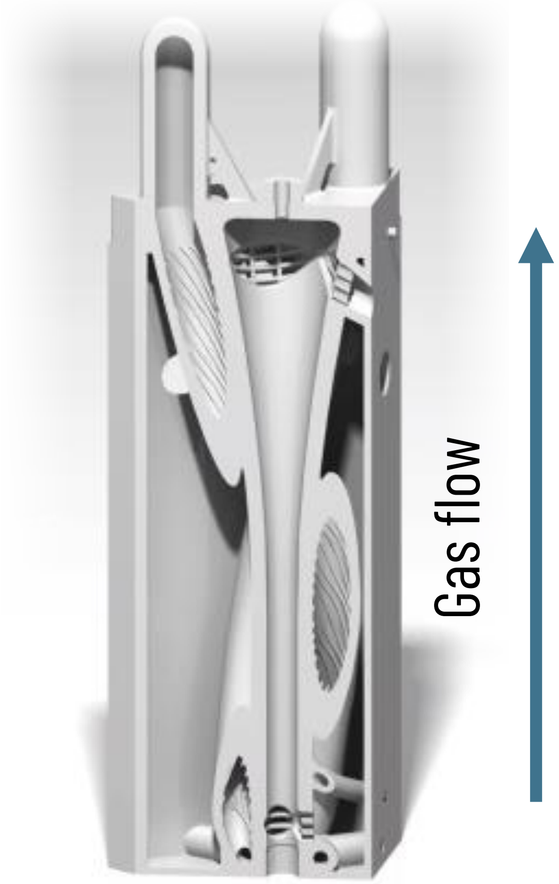
ADDmeth1: Results on synthesis power

- The reactor exhibits **the desired temperature profile**
- However, **at higher power levels**, the **hotspot shifts towards the rear**
- The hotspot in the lower section does not yet have the desired profile





Department of Chemical and Bioengineering (CBI) • Chair of Energy Process Engineering • Prof. Dr.-Ing. Jürgen Karl • Prof. Dr. Katharina Herkendell

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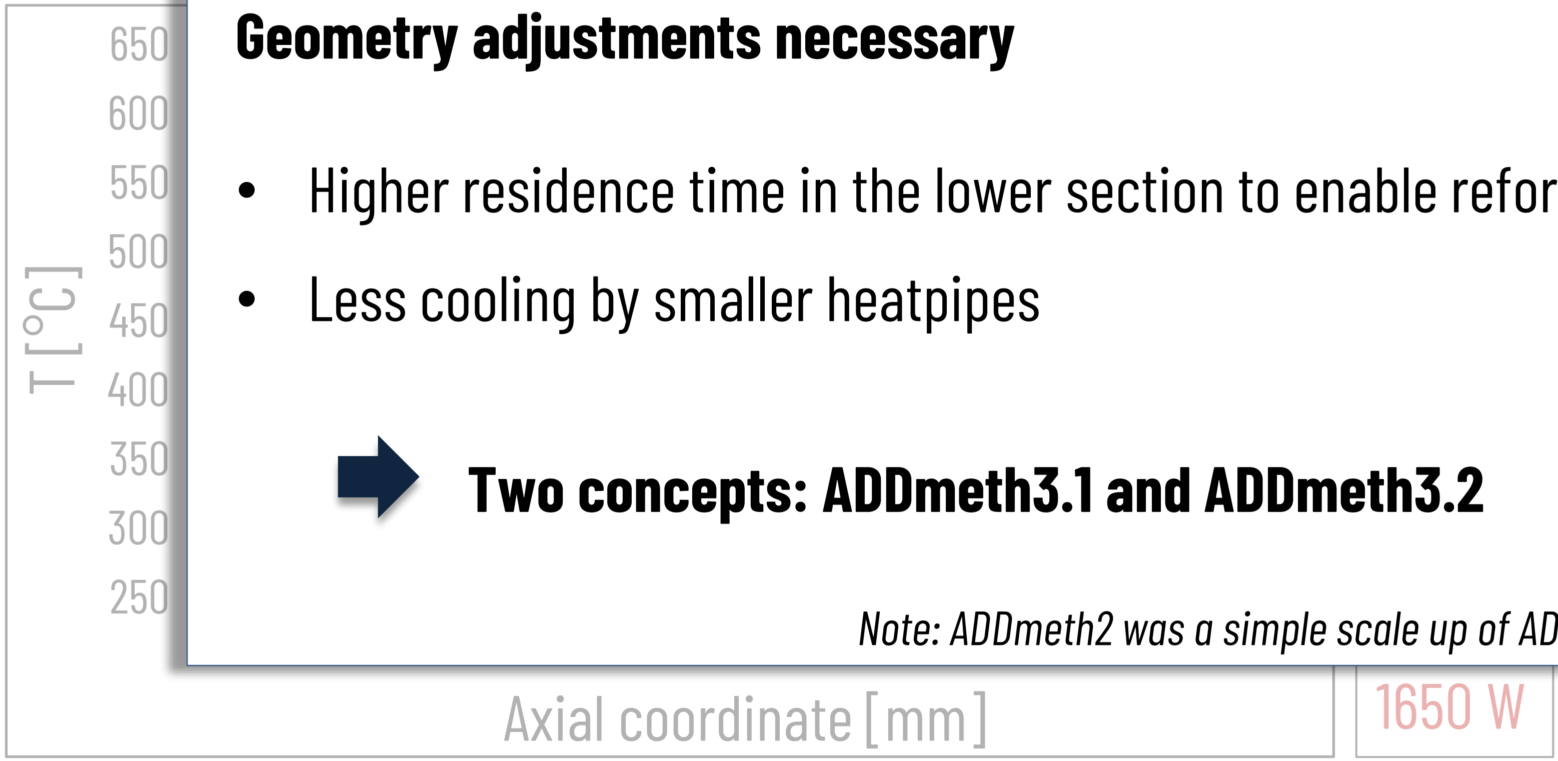
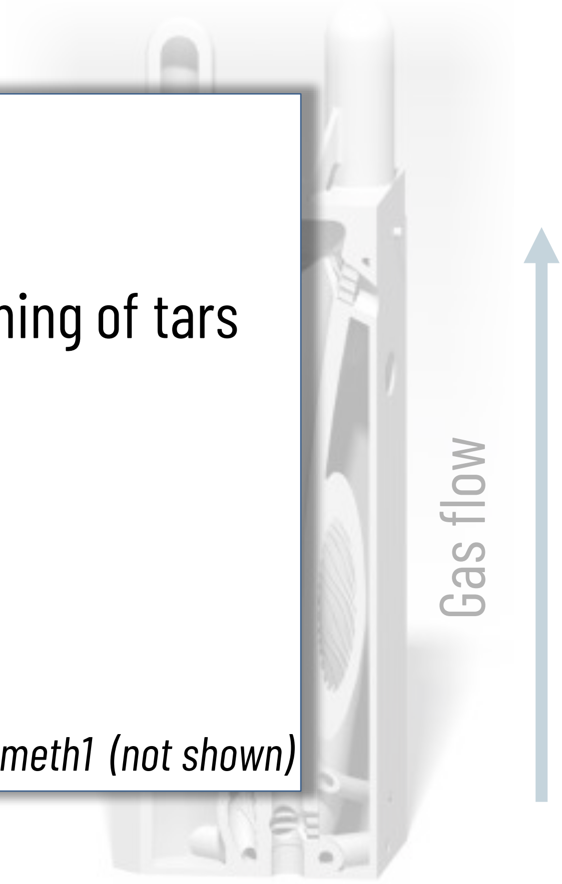
ADDmeth1: Results on synthesis power

- The reactor exhibits **the desired temperature profile** (during **pure CO2 methanation**)
- However, **at higher power levels**, the **hotspot shifts towards the rear**
- The hotspot in the lower section does not yet have the desired profile





Geometry adjustments necessary

- Higher residence time in the lower section to enable reforming of tars
- Less cooling by smaller heatpipes

➡ **Two concepts: ADDmeth3.1 and ADDmeth3.2**

Note: ADDmeth2 was a simple scale up of ADDmeth1 (not shown)

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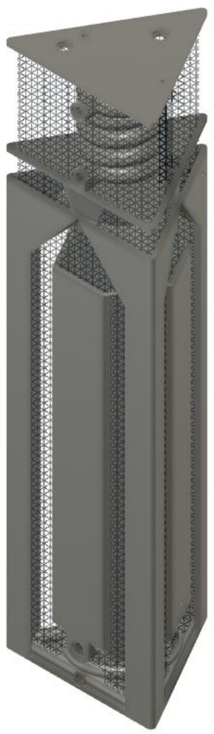
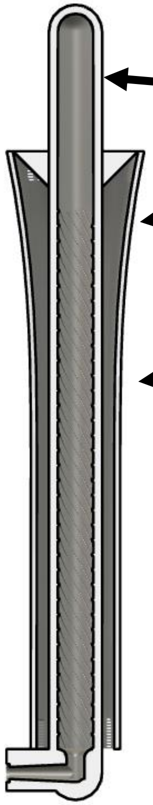
Variant 1 (ADDmeth3.1)

- The heat pipe is **centrally positioned**, and the reaction channel is arranged concentrically around it
- The **cross-section** in the lower region is **larger**, leading to an **increase in local residence time**
- Using a single heat pipe instead of three enhances the heat dissipation design

80 mm edge,
276 mm height

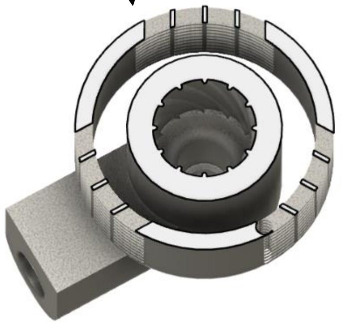




Central Heatpipe

Conical widened reaction channel

The reaction channel is arranged concentrically around the heat pipe



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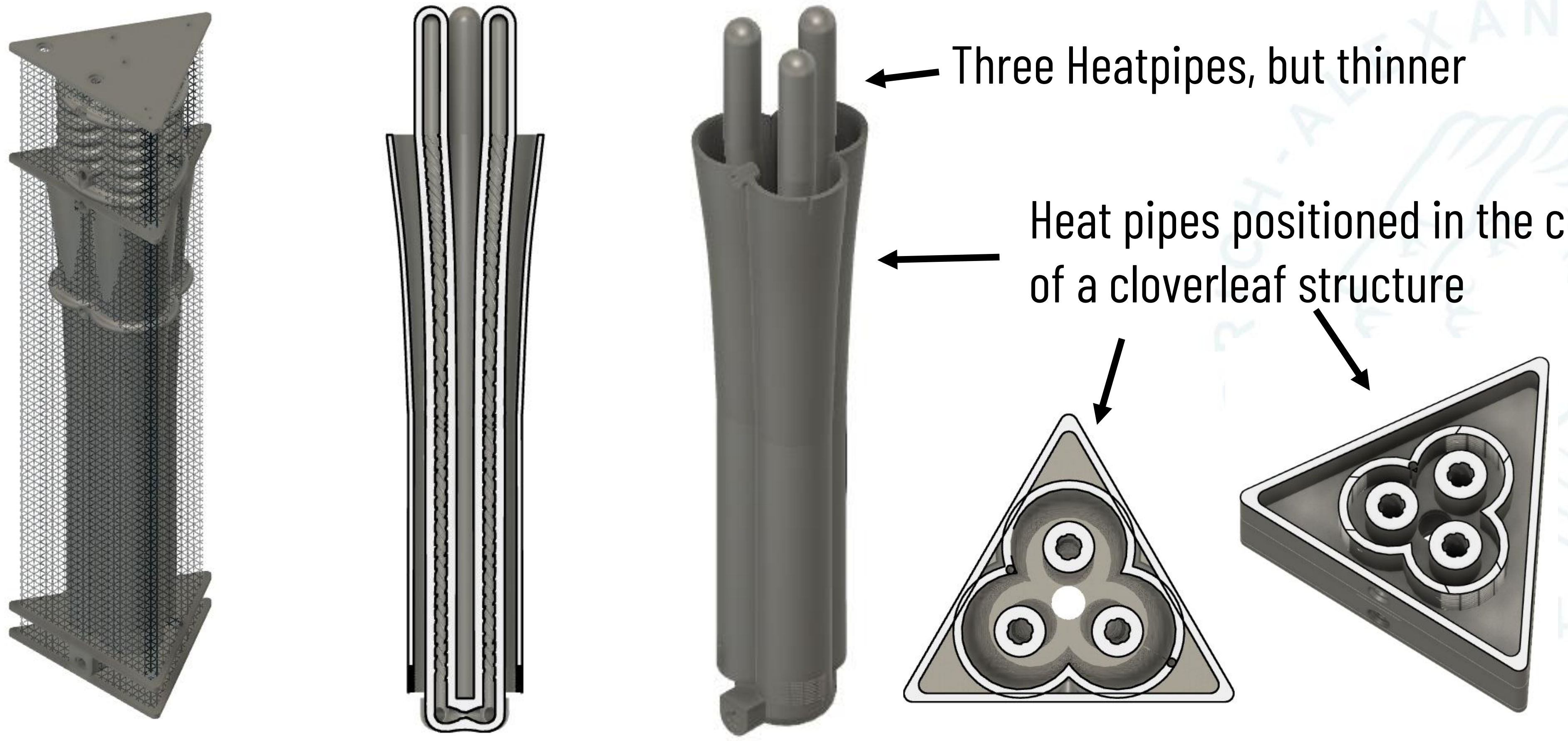
Variant 2 (ADDmeth3.2)

- Three heat pipes with reduced diameter are arranged in a cloverleaf structure
- The heat pipes follow the widening of the reaction channel in the upper part

80 mm edge,
266 mm height



Three Heatpipes, but thinner

Heat pipes positioned in the center of a cloverleaf structure

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Comparison of different ADDmeth designs

- **Comparison of catalyst volume** (leads to higher synthesis power)

ADDmeth1

Variant 1
~ Factor **2,9**

Variant 2
~ Factor **5,2**

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Comparison of different ADDmeth designs

- **Comparison of the cross-section** in the lower section of the reaction channel (enables higher temperature)

ADDmeth1

~50 mm^2

Variant 1
~ Factor **5,5**

~275 mm^2

Variant 2
~ Factor **11,7**

~585 mm^2

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New ADDmeth3 designs

- Both reactors build upon the learnings from the ADDmeth1 experiments
- The **catalyst bed** per unit cell is significantly **larger than in ADDmeth1**, and the local **residence time** in the lower section of the reactor is significantly **improved**.

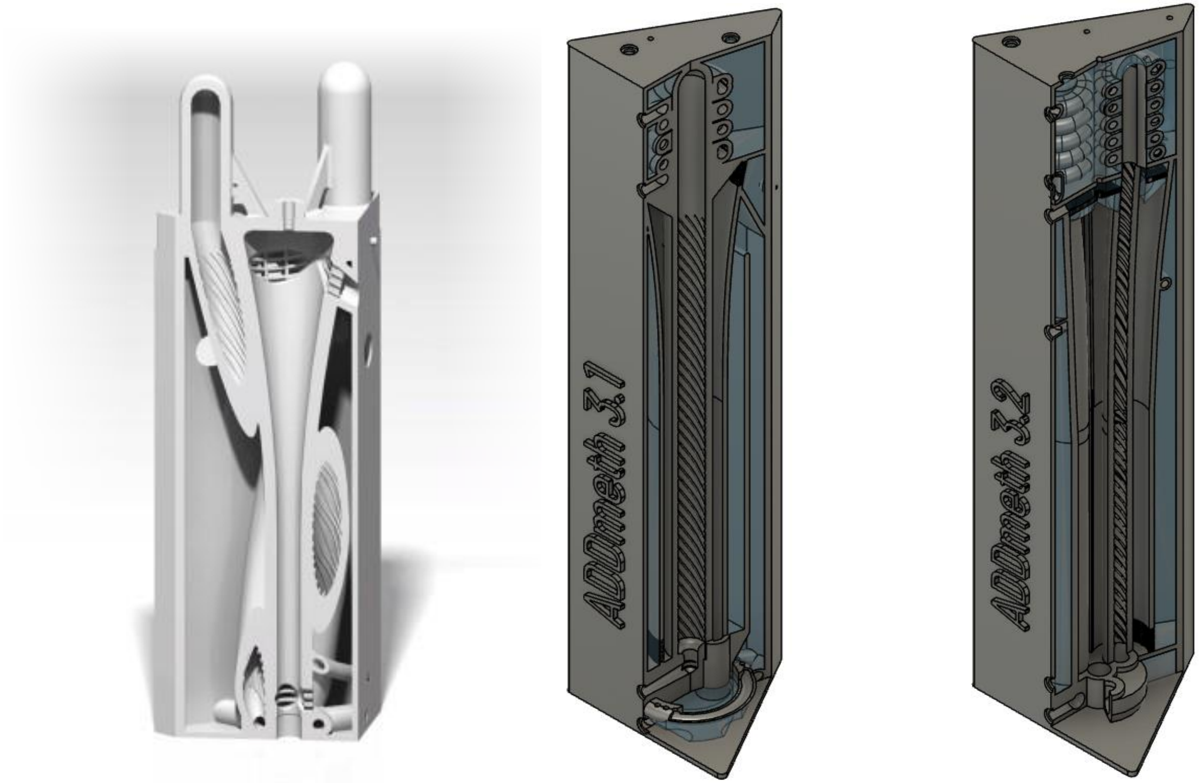


Abb. 18: Vergleich der ADDmeth Designs in der Schnittansicht

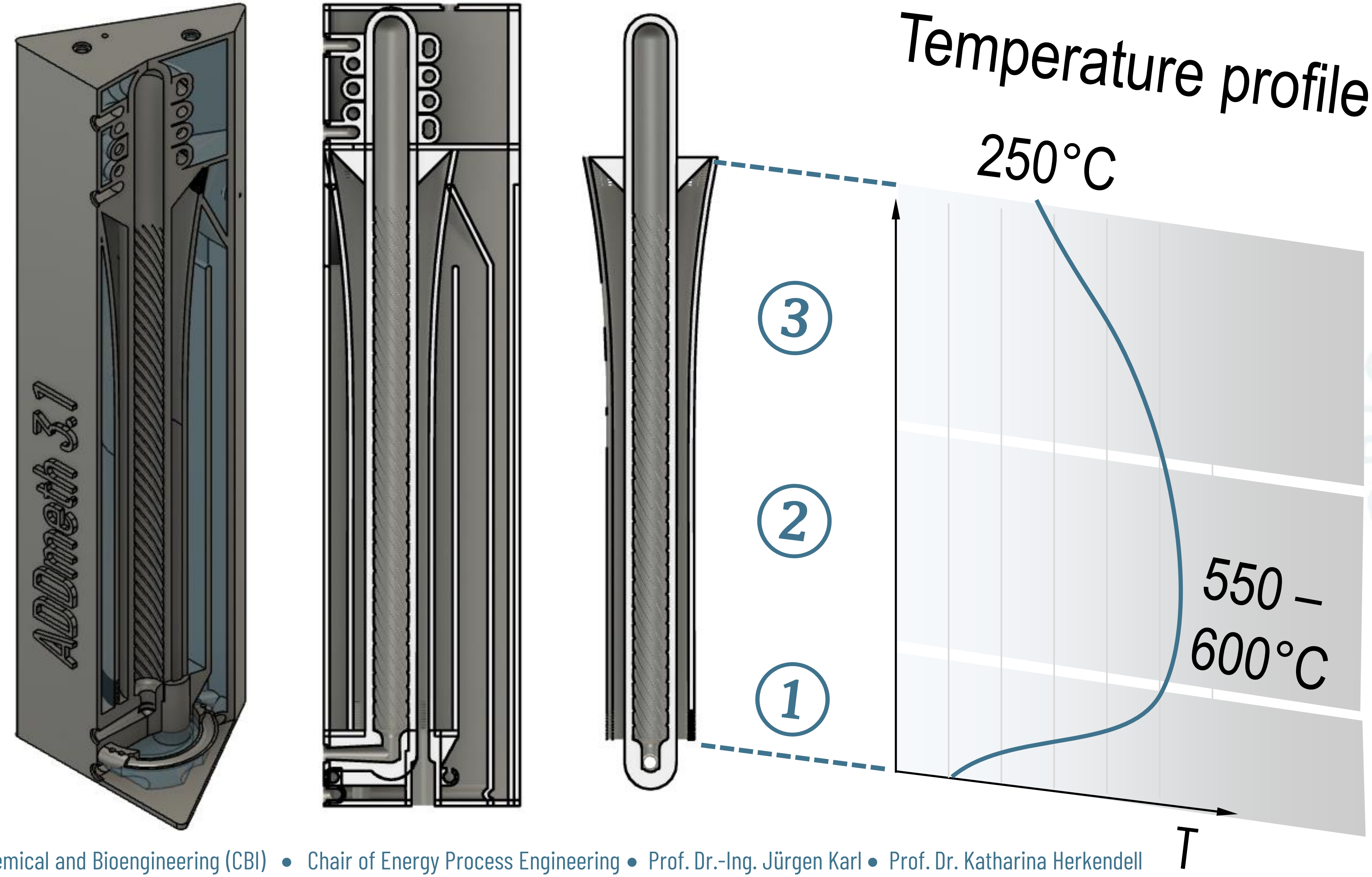
ADDmeth1 ADDmeth3.1 ADDmeth3.2

- The **heat pipes** are **better tailored** to accommodate the released reaction heat

Additional features:

- Improved heat transfer
- 3D-printed steam generator

Result: Methanation reactor with in-situ co-reforming of tars



1. Reaction starts
2. Tar reforming
3. Improve methane yield w.r.t. equilibrium

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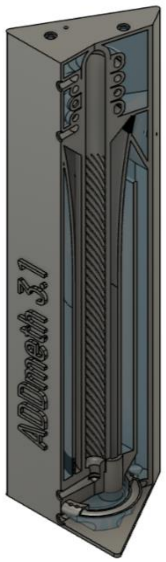
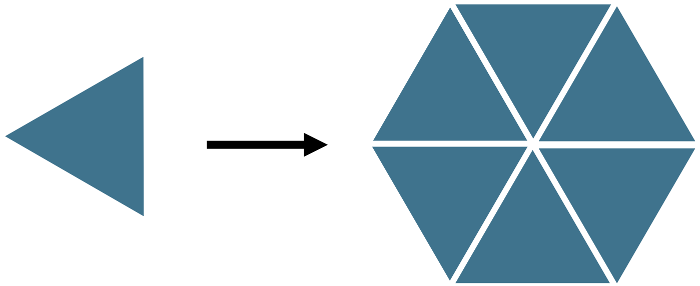
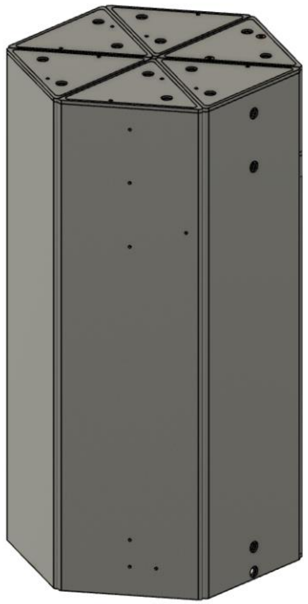
Outlook

- After characterization in the laboratory, the presented 5 kW unit cell is scaled up by connecting multiple triangular cells to form a 20 kW cluster.

Upscale:







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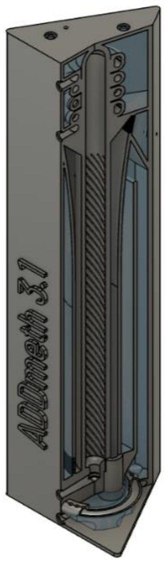

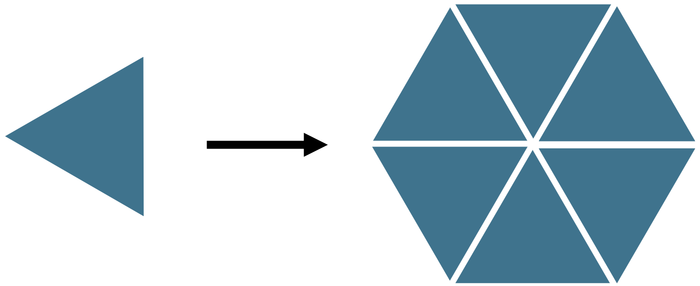

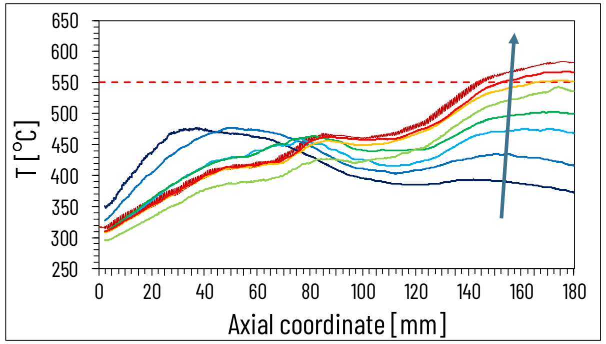

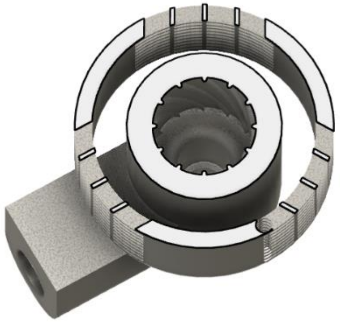

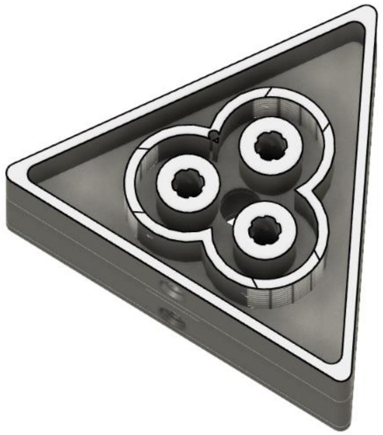

Thank you for your attention!